NASA/TM—2010-216896

Effects of Hydrocarbon-Based Grease on Rapid Prototype Material Used for Grease Retention Shrouds

Andrew J. Zakrajsek, Daniel J. Valco, and Kenneth W. Street, Jr.
Glenn Research Center, Cleveland, Ohio

December 2010

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 443–757–5803

- Telephone the NASA STI Help Desk at 443–757–5802

- Write to:
  NASA Center for AeroSpace Information (CASI)
  7115 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2010-216896

Effects of Hydrocarbon-Based Grease on Rapid Prototype Material Used for Grease Retention Shrouds

Andrew J. Zakrajsek, Daniel J. Valco, and Kenneth W. Street, Jr.
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

December 2010

Acknowledgments

The authors wish to acknowledge support from the following individuals. Tracy Cantley, the Rapid Prototype operator who manufactured the parts, Richard Mondry for his assistance in obtaining surface profiles, Mike Handschuh, and Anna Hartman for providing the Model for Test Sheets.

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076–1320

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312

Available electronically at http://gltrs.grc.nasa.gov

Effects of Hydrocarbon-Based Grease on Rapid Prototype Material Used for Grease Retention Shrouds

Andrew J. Zakrajsek, Daniel J. Valco, and Kenneth W. Street, Jr.
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

Effects of hydrocarbon-based greases on specific rapid prototype (RP) materials used to fabricate grease retention shrouds (GRS) were explored in this study. Grease retention shrouds are being considered as a way to maintain adequate grease lubrication at the gear mesh in a prototype research transmission system. Due to their design and manufacturing flexibility, rapid prototype materials were chosen for the grease retention shrouds. In order to gain a better understanding of the short and long term effects grease pose on RP materials, research was conducted on the interaction of hydrocarbon-based grease with RP materials. The materials used in this study were durable polyamide (nylon), acrylonitrile butadiene styrene (ABS), and WaterClear 10120. Testing was conducted using Mobilgrease 28 and Syn-Tech 3913G grease (gear coupling grease). These greases were selected due to their regular use with mechanical components.

To investigate the effect that grease has on RP materials, the following methods were used to obtain qualitative and quantitative data: Fourier transform infrared spectroscopy (FT-IR), interference profilometer measurements, digital camera imaging, physical shape measurement, and visual observations. To record the changes in the RP materials due to contact with the grease, data was taken before and after the grease application. Results showed that the WaterClear 10120 RP material provided the best resistance to grease penetration as compared to nylon and ABS RP materials. The manufacturing process, and thus resulting surface conditions of the RP material, played a key role in the grease penetration properties and resilience of these materials.

Introduction

The grease retention shroud (GRS) is a relatively new concept that is designed to maintain grease lubrication at the mesh of two contacting gears. The GRS has two main functions; catching the grease cast off during gear rotation, and reapplying the grease to the gear mesh. An illustration of a GRS concept developed at Glenn Research Center is seen in Figure 1. In a traditional grease lubricated transmission, as a gear rotates, grease is thrown off and deposits around the casing (Ref. 1). As a result, only a thin film is left on the gear teeth that must lubricate the teeth through every subsequent mesh cycle. Without replenishing grease on the gear tooth, the grease breaks down faster, thus allowing gear tooth surface wear to occur at a higher rate. The GRS prevents this by catching the grease on the walls of the shroud. In theory, when the buildup is thick enough on the shroud walls, the teeth will encounter the grease buildup and capture the additional grease, thereby returning the grease into the gear mesh. This operation not only maintains the grease where it is needed, but also acts to recycle the grease as it goes through the mesh/rotational release/captures process.

The GRS concept was first applied to a research gearbox developed for the four-man lunar rover test bed vehicle (Chariot) at Johnson Space Center (JSC) and later Glenn Research Center (GRC) (Ref. 2). As a result of the design and manufacturing flexibility provided by the rapid prototype (RP) method and the non-load bearing nature of the shroud, the shroud for the Chariot gearbox was built using this method. A GRS or any part in a mechanical assembly made out of rapid prototyped material has additional benefits. The weight of the piece is significantly less than steel, aluminum, or any other type of metal if made using RP materials. The RP process is significantly faster for manufacturing custom parts due to the direct

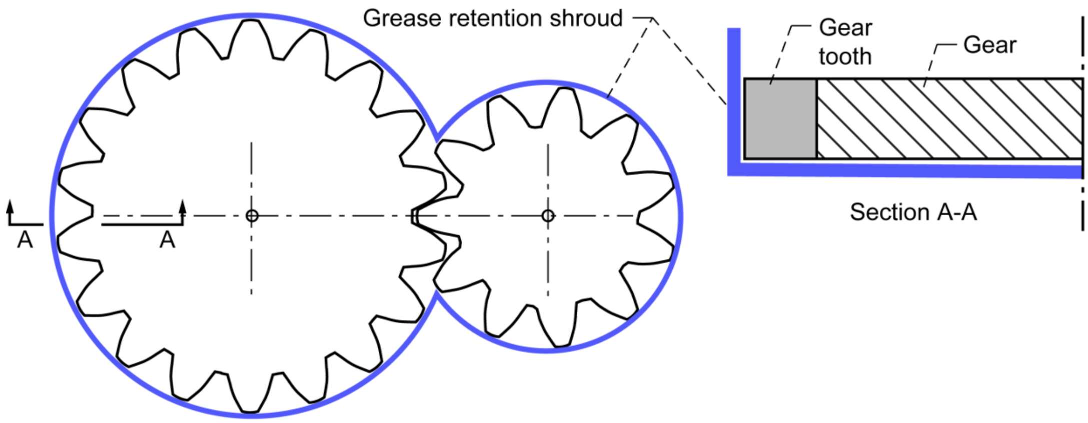

Figure 1.—Grease retention shroud concept: left - top view; right - side view.

interface of the computer modeler with the process equipment. Using RP would be cheaper than purchasing a manufactured shroud because of the complexity of the model and the difficulty involved to computer numerical control (CNC) machine a grease retention shroud.

The research gearbox is currently being tested on the Chariot lunar rover test-bed vehicle at JSC. Since the RP shrouds were used in this research gearbox and the effects of the grease on the RP material used is not well understood, this study was initiated to identify any compatibility issues that may arise in this specific application and for future utility.

Rapid Prototype Manufacturing Process

To simplify this study only three RP materials where used and two gear greases. Each material was tested with the same gear grease in duplicate. The materials manufacturing process is of importance for this study. Each material piece was sent to its own RP machine via a modeling program. Each machine then took the file and produced each part using a process compatible to the materials composition. As seen in the results, the manufacturing process for these RP materials played a large part in how the material was affected by the hydrocarbon-based greases. A FT-IR spectrum of all RP materials can be seen in Appendix I.

When the RP material composed of durable polyamide (nylon) (Ref. 3) was made, an initial layer of powder is produced. This procedure is a volume process which fills an imaginary cube with layer-by-layer of powder. As the powder layers build, the machine sinters the powder to solidify the part layer-by-layer. Then, a sintering process heats the powder melting it into the desired shape. This can be a problematic process if subsequent powder layers are not completely melting and flowing into the prior structure, creating voids or crevices. This is observed primarily on the surface of the layers due to the powder being too coarse for complete melting. This is a result of the machine recycling some of the powder from a previous fabrication session.

The second RP material made of ABS (Ref. 4) was constructed by melting the starting material into a liquid-solid state, which was then, applied starting from the bottom up to build the part. The ABS material comes in a thin rope, around an eighth of an inch diameter similar to the material used in lawn trimmers. The material build is started at what will become the base of the component, followed by layering thin cylindrical materials in the desired final form. When the final form is reached, the material is sintered. After the first layer cools the next layer is laid on top and the process continues throughout the build. This produces a finish with long ridges running through the material. These ridges or crevices are found throughout the material in an equally spaced pattern.

The final RP material produced from WaterClear 10120 (Ref. 5) was formed from a liquid building from the bottom up. The liquid is placed in thin layers on the building piece where a sintering laser heats the material to produce the desired shape. This works well because the liquid will fill in any of the crevices and voids to allow for a smooth finish. The liquid is clear forming transparent parts.

Test Procedures

A RP test sheet, as seen in Figure 2, was divided into individual specimen at the edges to produce eight smaller rectangles and then labeled. There were three sheets made for each of the three different RP materials. An interference profilometer (Ref. 6) was then used to measure the original profile of the surface of the well in each test section of the material to provide a control to which the results could be compared. The datum was also set by photographing the specimen before grease application and visually inspecting the specimen.

Single drops of grease, 0.3 cm (1/8 in.) in diameter, were placed in each of the four sections on the rectangles and above the Roman numeral in the designed well. The drops of grease were left on the test piece for a measured period of time. For the roman numerals I and II, Mobilgrease 28 (Ref. 7) was applied, while for numerals III and IV Syn-Tech 3913G grease (Ref. 8) was applied. The samples were left undisturbed in an open plastic housing to prevent unwanted contamination until the designated time of inspection. Overall, the test lasted 18 days. Specified times and other testing parameters are given in Table 1. The letters A to H were written on each test piece before the test representing the eight different exposure durations. Each test included taking visual observations and a photograph while the drop of grease was still on the RP materials test piece. After the specified time, the piece was mechanically cleaned by physically removing the grease. Initially, solvents were proposed to remove the grease, but the possible effects of the solvents on the RP materials were unknown at that time. Therefore, the grease was removed mechanically to prevent the experiment from being compromised by deleterious effects of the solvents. On the test termination day, three different pieces of material were examined at the same time. All visual observations and surface profiles were recorded simultaneously. Later it was determined that grease removal could be done more effectively with solvents and the surface profilometry was repeated after solvent extraction of the grease.

The test specimens were then imaged using the interference profilometer to measure surface roughness. The test procedure for each piece as explained previously, took approximately 45 min to complete. This study was conducted under ambient conditions in an air-conditioned lab (16 °C).

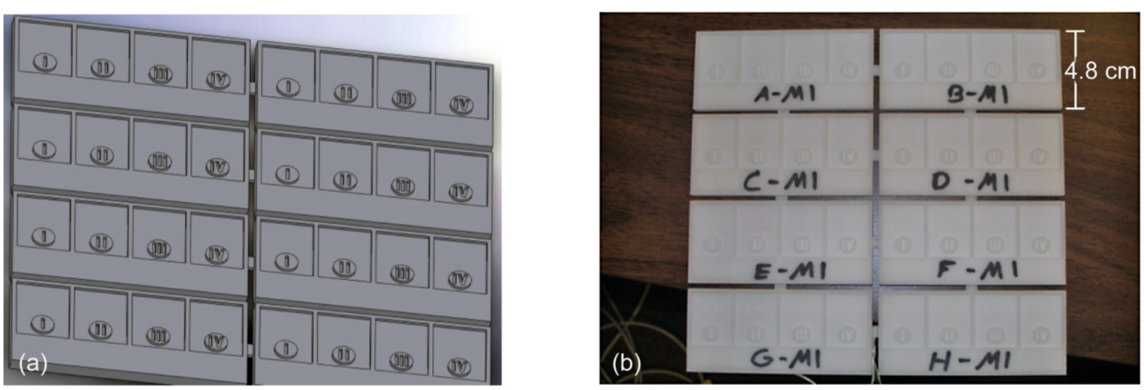

Figure 2.—GRS test specimen. (a) Modeling drawing of the rapid prototyped sheets used for grease testing. Each row contains four wells labeled with Roman numerals. (b) Picture of actual test sheet for nylon.

TABLE 1.—GREASE REMOVAL TIME FOR EACH SPECIMEN

Sample	Duration, hr
A	19
B	47
C	67
D	90
E	163
F	239
G	331
H	428

TABLE 2.—DISPLAYS SOLVENTS TESTED ON RP MATERIAL AND RESULTS

Solvent	Nylon	ABS	WaterClear
Hexanes	S	N	N
DCM	N	D	S
D- Dissolved N- No Damage S- Minor Swelling			

TABLE 3.—THICKNESS OF SAMPLE MATERIALS BEFORE AND AFTER SOLVENT SOAK WITH SONICATION

	Nylon		ABS		WaterClear	
	Thickness, cm		Thickness, cm		Thickness, cm	
Solvent	Before	After	Before	After	Before	After
Hexanes	0.638	0.653	0.640	0.640	0.638	0.638
DCM	0.639	0.639	0.636	NA	0.635	0.640

TABLE 4.—THICKNESS OF SAMPLE MATERIALS AFTER TIMED EXPOSURE TO GREASE

	Mobilgrease, thickness, mm			Syn-tech 3913G, thickness, mm		
Day	Nylon	ABS	WaterClear	Nylon	ABS	WaterClear
0	2.77	2.80	2.49	2.82	3.03	2.50
7	2.76	2.77	2.47	2.86	3.01	2.48
42	2.77	2.76	2.48	2.83	3.01	2.49

When the testing duration and accompanying photographic and surface profilometry was completed, specimens were sectioned to obtain clean materials for solvent testing. Small pieces of RP material (approximately 6×12 mm) were soaked and sonicated for 1 min in either a mixture hexanes or methylene chloride. The samples were dried and visually inspected for damage. A virgin sample and the soaked samples were submitted for attenuated total reflectance Fourier transform infrared, FT-IR, spectroscopic analysis. The FT-IR was equipped with a microscope using an MCT detector and an attenuated total reflectance objective with a zinc selenide crystal.

The RP materials were examined for damage from common solvents employed in grease removal. Virgin RP material specimens were measured for thickness and then soaked in analytical grade solvents, hexanes (contains mixed isomers) and methylene chloride (DCM), for 1 min. in an ultrasonic bath. Afterwards the samples were removed and dried. They were then visually inspected, their thickness remeasured and subjected to FT-IR for chemical characterization. Visual inspection data appears in Table 2 and swelling data in Table 3.

Independent grease-swelling experiments were conducted with coupons approximately 10 by 10 by 3 mm. A spot of grease approximately 6 mm in diameter was placed on duplicate coupons and allowed to stand for 7 days. Afterwards the grease was physically removed and the coupon thickness remeasured. Grease was reapplied and allowed to remain an additional 35 days. The sample was again mechanically cleaned by wiping and the thickness was measured and averaged for duplicates. Data for this experiment appears in Table 4.

Results and Discussion

From the solvent exposure studies, Tables 2 and 3, it is necessary to carefully test materials and procedures when using RP materials. Some RP materials like the ABS are soluble in solvents like DCM and others appear to swell slightly, like the WaterClear in DCM and nylon in hexanes. The FT-IR spectrum of the DCM soaked ABS material indicated some structural damage existed, although no damage was indicated post-extraction for any other material/solvent combination. FT-IR spectroscopy was also used on the solvent-cleaned RP material to determine whether the grease had chemically damaged the material. Small spectral changes indicated that there was no damage to the RP materials and that the solvent effectively cleaned grease from the porous RP materials.

The RP materials underwent 18 days of grease exposure for spreading and surface texture, Table 1, and 42 days of exposure for swelling, Table 4. Discoloration of nylon and ABS RP materials occurred during exposure, indicating a change in the RP material. Discoloration of the nylon and ABS RP materials increased over time, while the WaterClear material showed no color change. The nylon saw the most significant absorption/discoloration after wiping, to the point where by the end of testing, the rectangular testing area was almost completely filled with a tainted hue of the grease's color. Since this test examined the behavior of a single drop of grease, it can be imagined that with a gear rotating and subsequent loss of larger volumes of grease over a long period of time this material could eventually allow the oil from the grease to penetrate the shroud and begin to leak. The ABS also absorbed a significant amount of the oil from the grease, based on the residual discoloration after mechanical cleaning.

The Mobilgrease 28 was spread/absorbed more significantly by the RP materials than the Syn-Tech 3913G grease. Therefore, unless one of these two greases is being used, additional testing should be performed to see how different greases will penetrate and/or spread over the RP materials. RP materials may promote the separation of greases. Observations of absorption behavior, as indicated by material discoloration after cleaning, can be seen more clearly in Figures 3 to 5, which show the first day versus the final day of testing. Measurements of the grease spread diameter versus exposure times are plotted in Figure 6.

To determine the microstructure of the surface, a Veeco interference profilometer was used to record the surface profile. Differences between scans before grease application and after test completion are shown in Figures 7 to 12 and in tabulated Surface Roughness, Ra, data in Appendix II. In Figures 7 to 12 the grease was mechanically removed by wiping and using an appropriate solvent for the RP material. Figures 7 to 12 are all from the 428 hr tests, with the coupling grease.

In Figures 7 and 8 the nylon appears to have underwent a major change. However, the roughness only changes from 10.1 to 10.6 µm which is not a large surface change. The two scales for the nylon, before and after grease application, are 105 and 71.8 µm, respectively.

In Figures 9 and 10, the ABS images from the interference profilometer are drastically different than what was observed with nylon. An error in obtaining accurate Ra values may be attributed to the "ridge pattern". This surface profile is attributed to the manufacturing of the material and how it is built from strands of cord producing a pattern of long, parallel alternating ridges and troughs across the surface of the material, allowing for grease entrapment and build-up. No evidence of material degradation by grease was evident from the surface profiles or Ra values. The ABS surface profiles for the virgin material and the grease-exposed RP material are 78.1 and 135 µm, respectively.

The WaterClear 10120 images from the interference profilometer seen in Figures 11 and 12 appear to be very similar. This can be attributed to the smooth surface finish of the WaterClear 10120 RP material. The WaterClear 10120 may perform differently from the two other RP materials due to the low relief allowing for closer tolerances between the GRS and gears. In addition, it does resist absorption of the grease better than the ABS or nylon RP materials. These attributes would contribute to the use of less grease in the gearing application. The WaterClear 10120 virgin material and the greased material had a scale of 6.75 and 4.32 µm, respectively, which is considered a non-significant change.

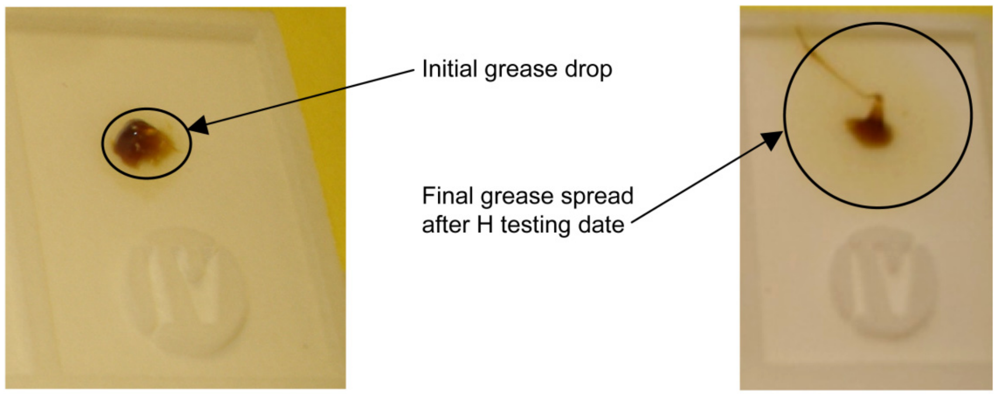

Figure 3.—Initial spot applied (left) and final spot diameter (right) with durable polyamide (nylon) material. Spreading can be seen concentrically around the center of applied Syn-Tech 3913G grease.

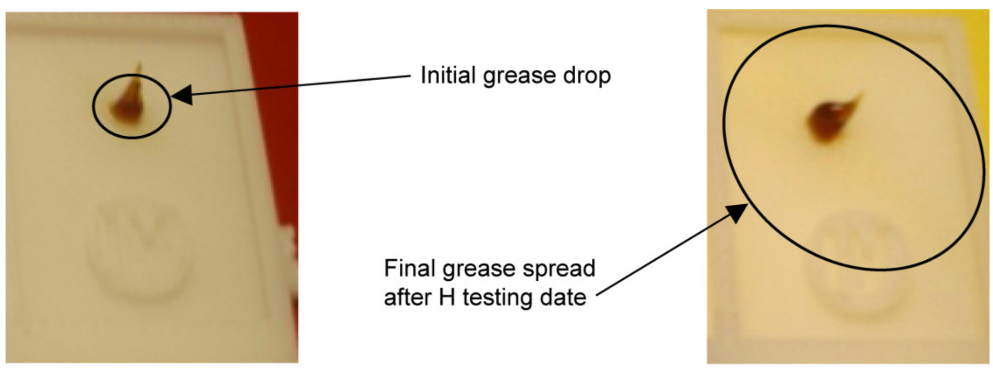

Figure 4.—Initial spot applied (left) and final spot diameter (right) with ABS material, the entire specimen has completely discolored from the spreading of the hydrocarbon-based Syn-Tech 3913G grease in the crevices of the material. The discoloring covers up the entire box especially with the Mobilgrease 28.

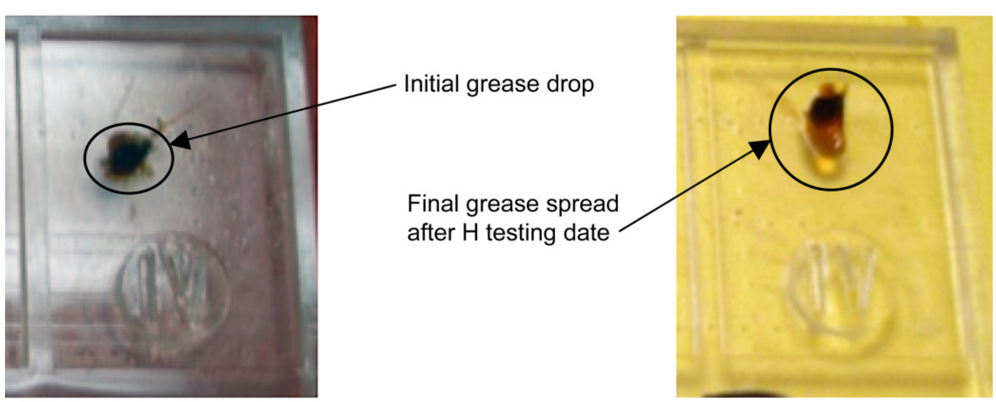

Figure 5.—Initial spot applied (left) and final spot diameter (right) with WaterClear 10120 material, there is no discoloration or spreading seen between the first and last test date with either grease.

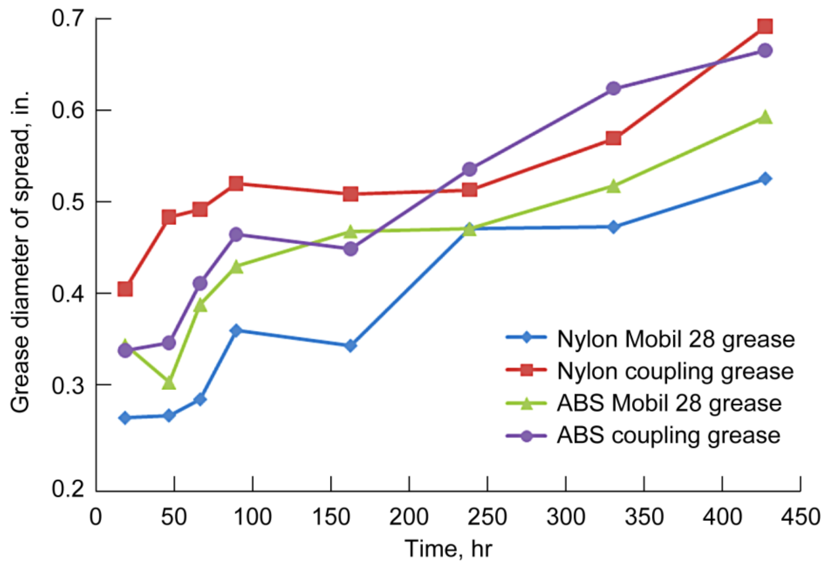

Figure 6.—Grease spread versus exposure time. The graph indicates time dependent spreading which varies depending on grease and RP material. WaterClear is not pictured because the diameter of the grease did not change. Nylon and ABS are pictured with the two separate greases and which all start at the first time reading.

Surface structure may be important in some applications. Another consideration is surface resistance to grease absorption, since clearances in GRS applications may be small to limit the quantity of grease employed during testing. Figures 7 to 12 show strikingly different surface finishes for the different RP materials. The nylon material has high relief with higher Ra values whereas the WaterClear shows very low relief and low Ra values. The ABS material showed parallel ridges with a large peak to valley depth formed during manufacture. The data in Appendix II may better demonstrate the ridge pattern than the actual roughness of the surface. In Figure 8, the nylon shows similar relief which is supported by the average roughness values before and after testing for both greases, suggesting that the grease does not react with this RP material. Nylon possesses an uneven topography which allows grease to seep into the material crevices causing the grease to stick to the material. Since this material saw the most noticeable change, additional images are included in Appendix III.

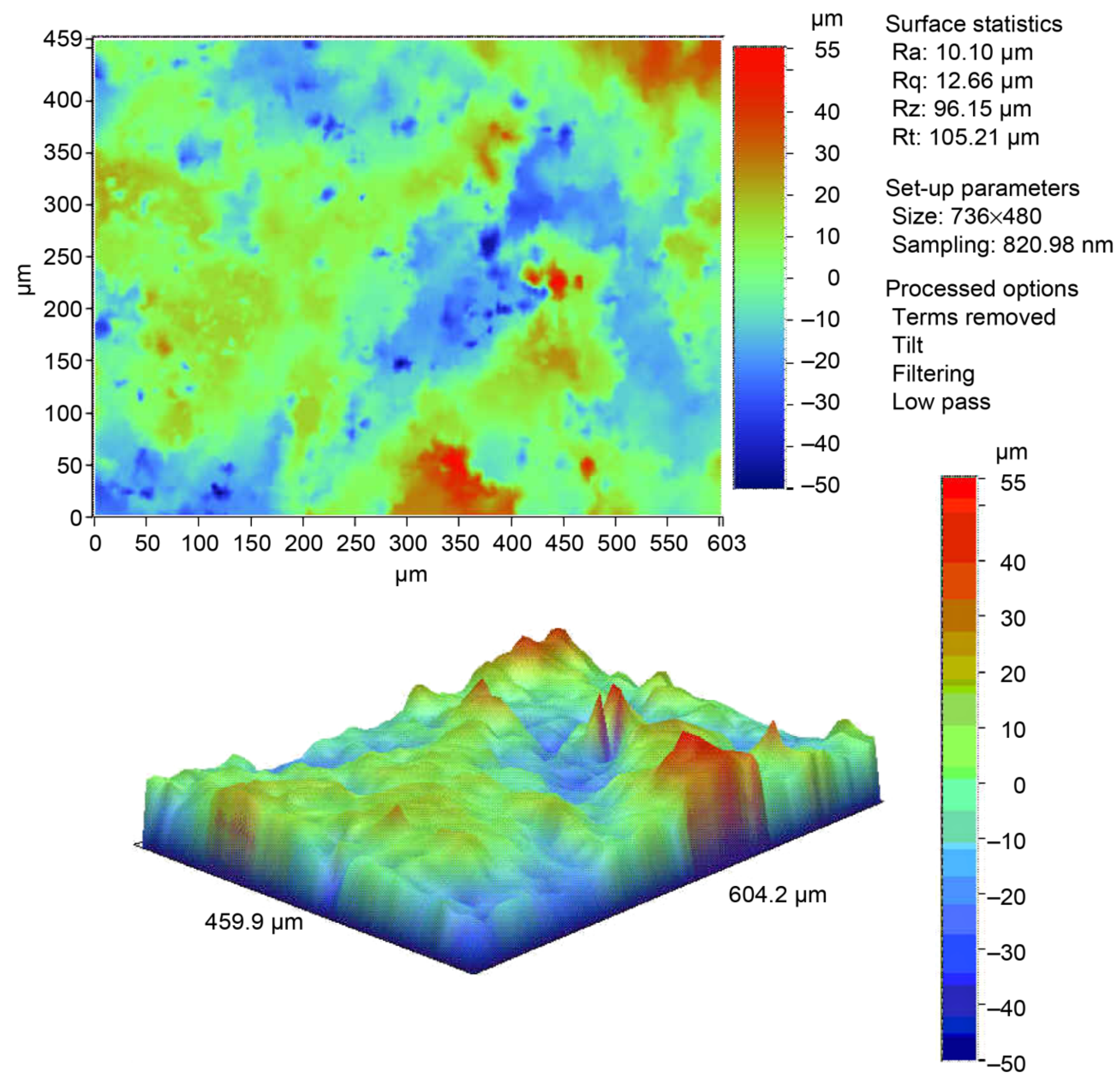

Figure 7.—Surface profile image of nylon RP material before grease exposure. Top image is topographical view, bottom image is 3-D view.

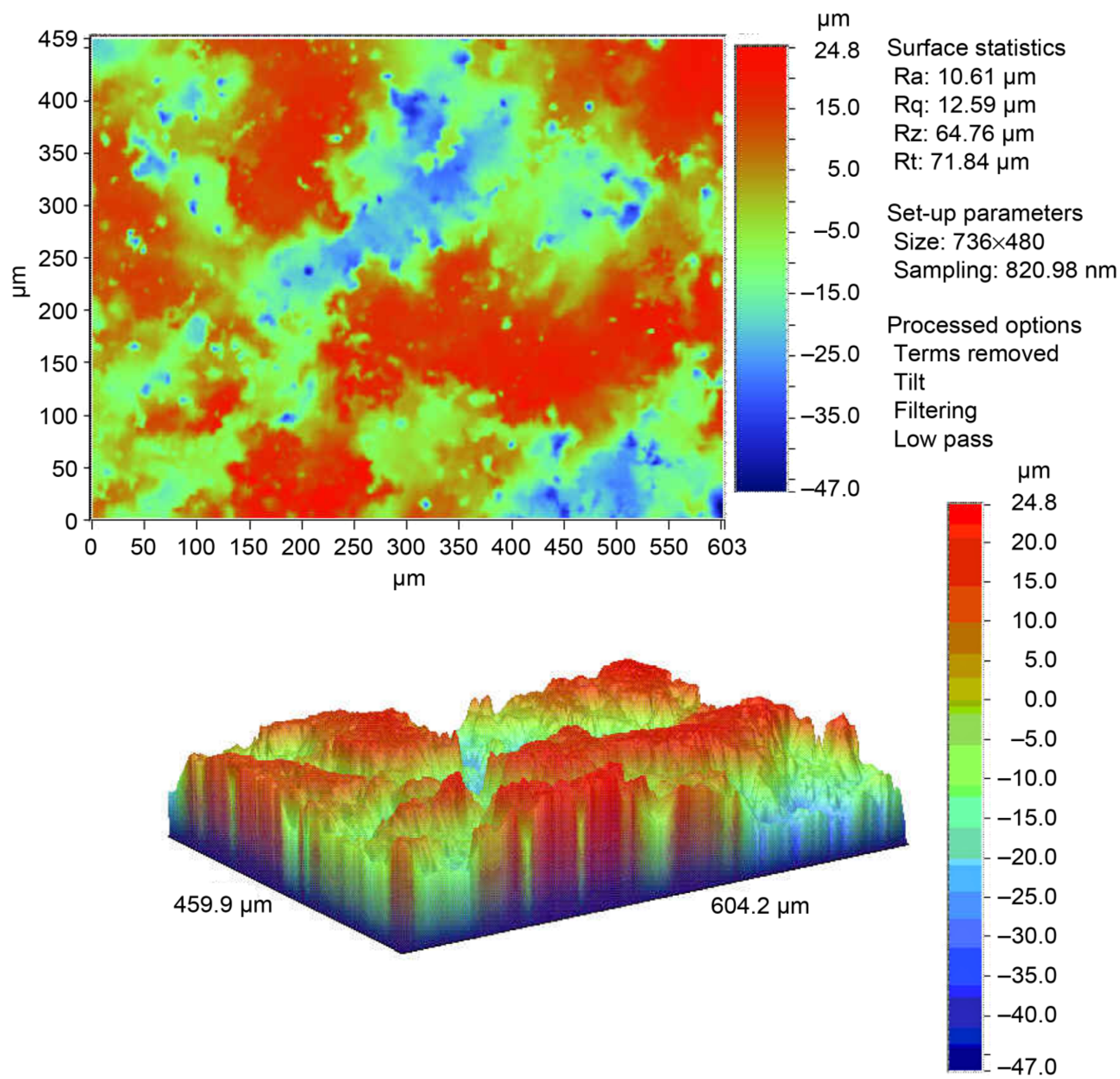

Figure 8.—Surface profile image of nylon RP material after 428 hr grease exposure. Top image is topographical view, bottom image is 3-D view.

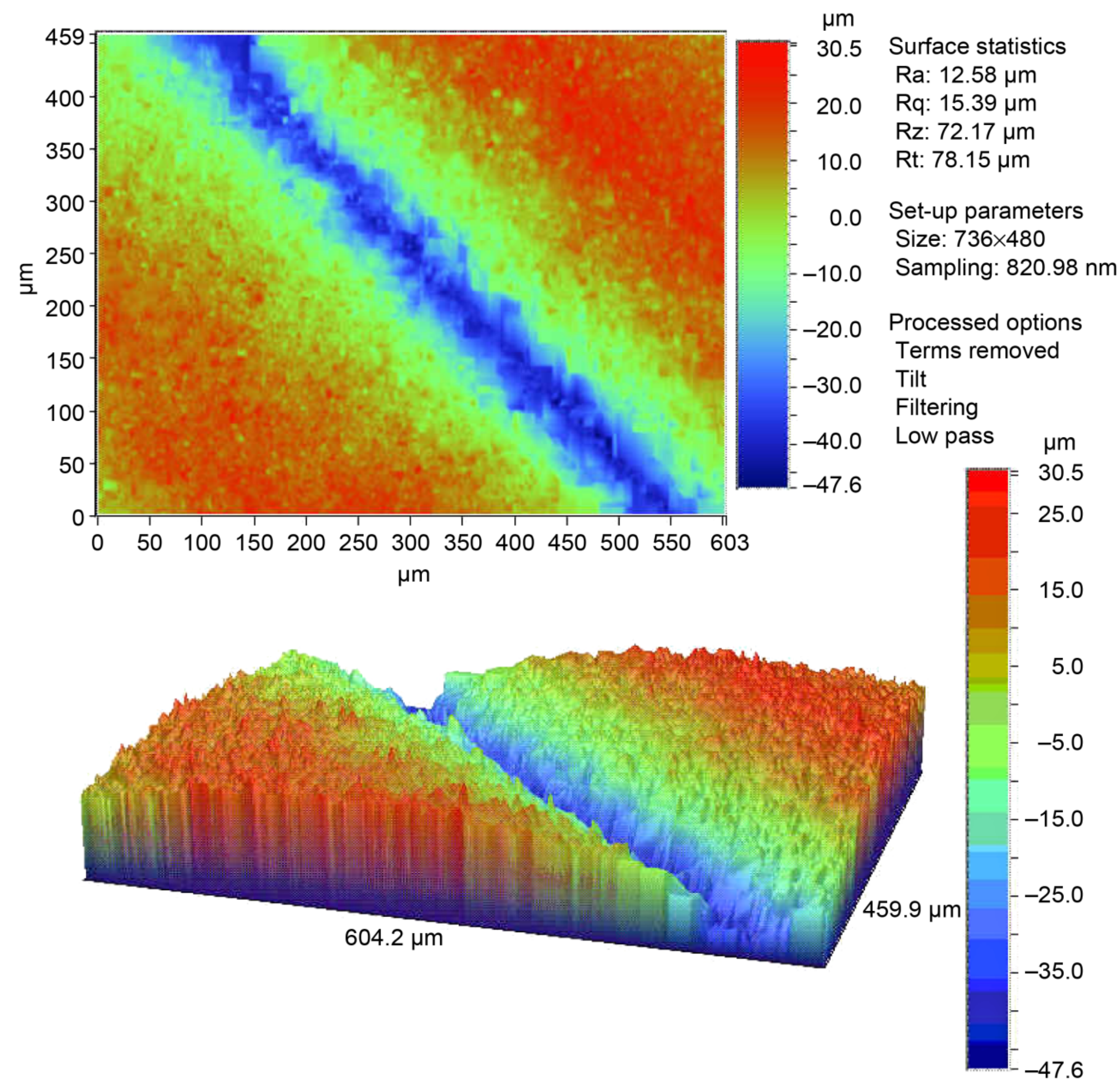

Figure 9.—Surface profile image of ABS RP material before grease exposure. Top image is topographical view, bottom image is 3-D view.

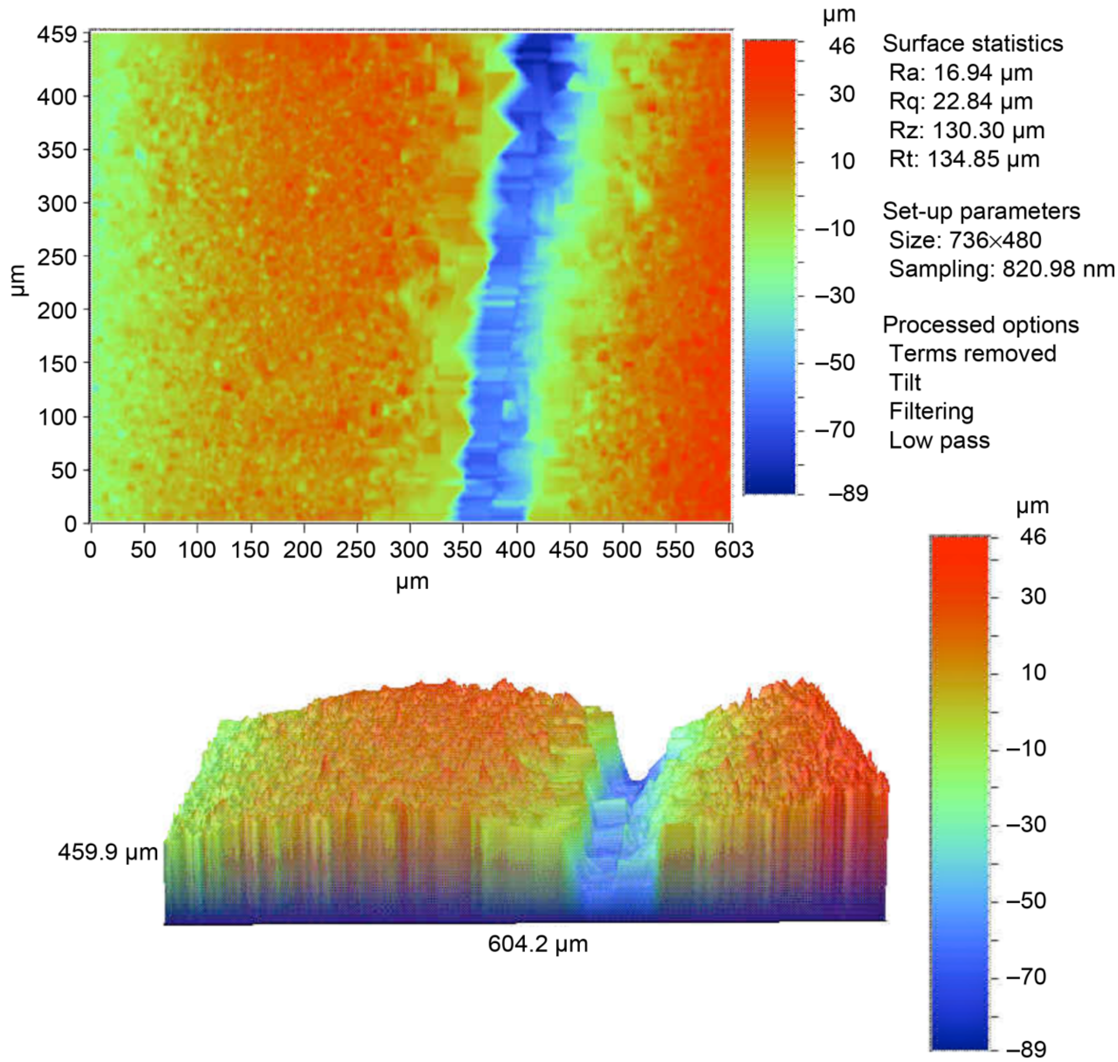

Figure 10.—Surface profile image of ABS RP material after 428 hr contact with grease. Top image is topographical view, bottom image is 3-D view.

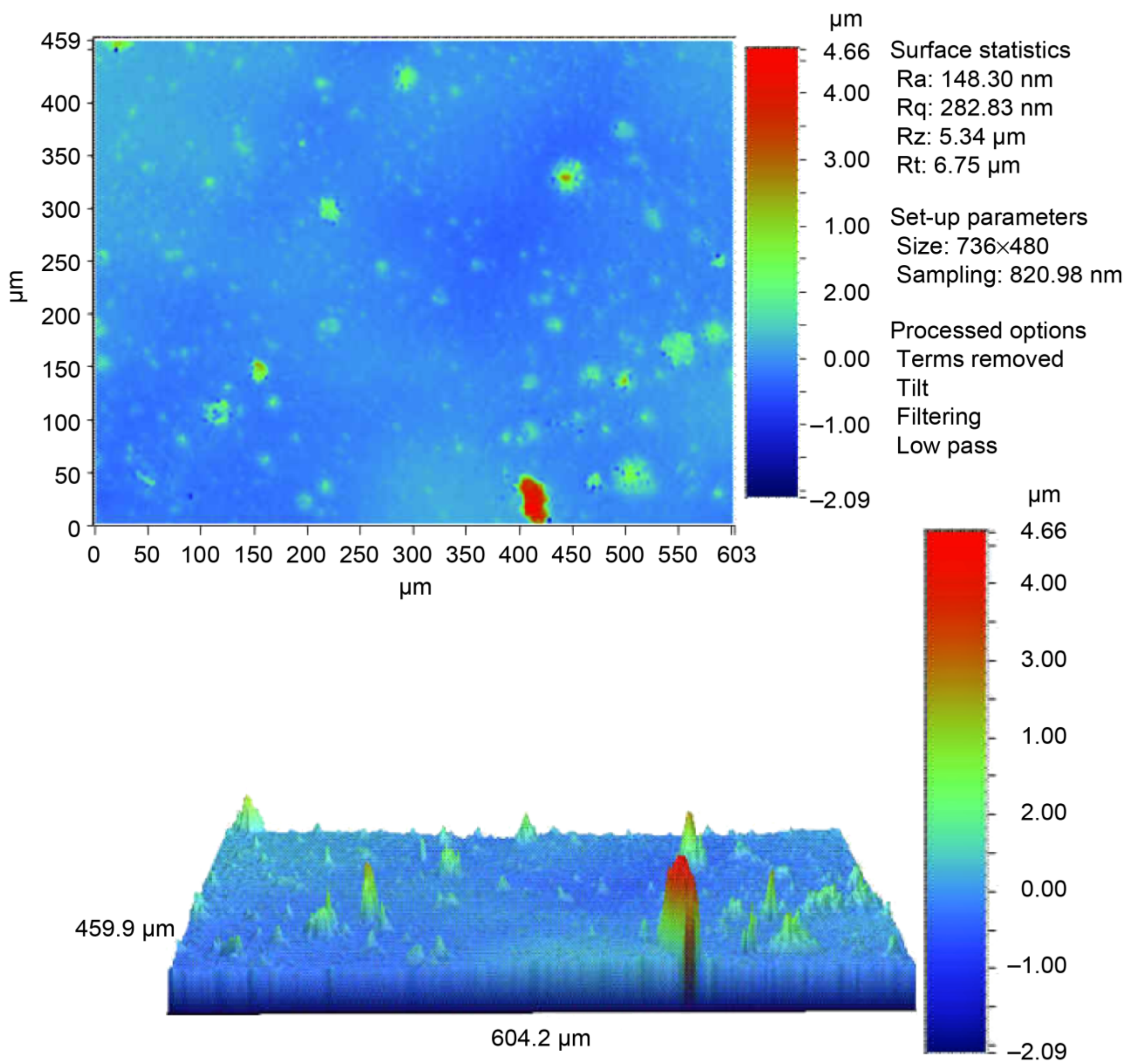

Figure 11.—Surface profile image of WaterClear 10120 RP material before grease exposure. Top image is topographical view, bottom image is 3-D view.

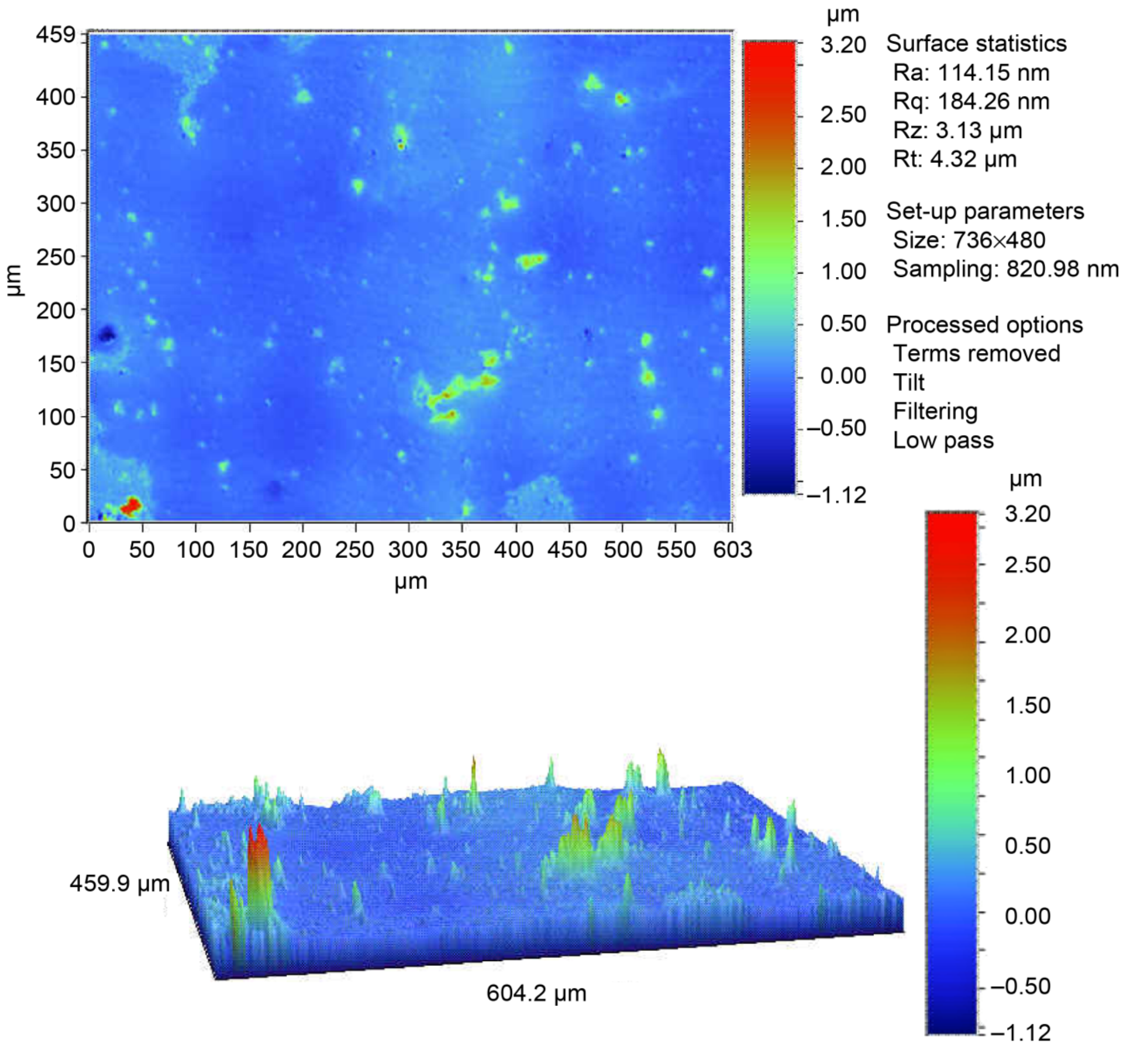

Figure 12.—Surface profile image of WaterClear 10120 RP material after 428 hr grease exposure. Top image is topographical view, bottom image is 3-D view.

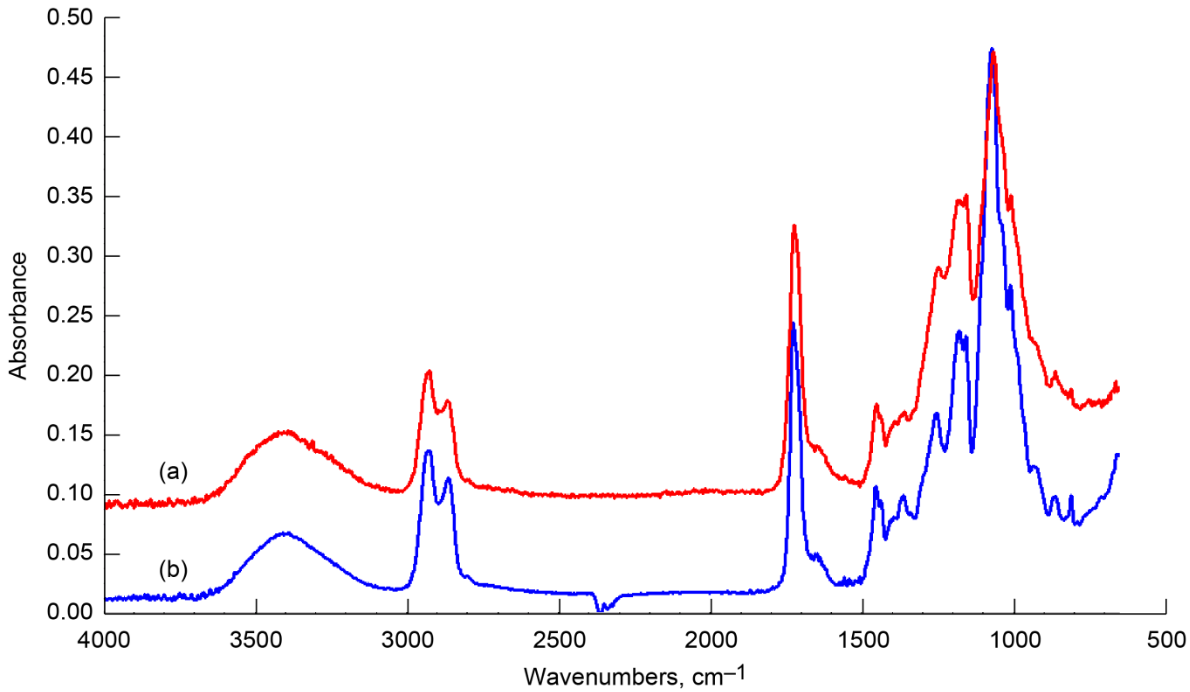

Figure 13.—FT-IR spectra of two materials (a) Accura_60 and (b) WaterClear 10120.

Perfluoroether-Based Grease Experiments

Experiments were conducted with a new form of rapid prototyped material, Acurra_60 Plastic by 3D systems (Ref. 9), and perfluoroether based grease (Ref. 2). This RP material is quite similar to WaterClear as indicated in the FT-IR spectra for each of these materials (Fig. 13). A threefold test with gears running at 150 rpm and a pressure of 250 psi were run for half a million cycles. No damage to the RP material properties were visually observed. At high loads and low speeds, using RP material as shrouding and perfluoropolyether-based grease may be acceptable for this application.

Conclusions

Effects of hydrocarbon-based greases on specific rapid prototype (RP) materials were explored in this study. The rapid prototype method was used to develop grease retention shrouds for a research gear transmission. The RP method was used to produce the shrouds due to the flexibility of the manufacturing process and the low weight of RP materials. Despite these favorable attributes, using RP materials in a fully-operational gearbox may be problematic. The three materials tested have different properties and processes for manufacturing that directly affect their ability to resist hydrocarbon grease penetration and possible degradation of the RP material itself. The WaterClear 10120 RP material provided the best resistance to grease penetration as compared with the nylon and ABS materials. From the test results, the WaterClear 10120 RP material appears to be the optimum material for constructing a GRS because almost no absorption of the grease occurred, during either the spreading or swelling experiments, and no noticeable damage to the surface was seen. This material also possesses lower relief (i.e., lower surface roughness) in the final product, allowing closer tolerance in manufacturing. The manufacturing process and thus the resulting surface conditions of the RP material play a key role in the grease penetration properties and resilience of these materials. In addition, testing the potential harm from using hydrocarbon-based grease and cleaning procedures on RP material were assessed. Finally, preliminary testing with Accura_60, a material very similar to WaterClear, using a perfluoropolyether-based grease showed no signs of wear or degradation throughout the 500,000 cycles of testing.

Suggested Future Testing

Further testing is needed to fully understand the long-term effects of hydrocarbon grease on rapid prototyped materials. The effect of operational temperatures, grease grade, and gear clearances on material integrity and tensile properties should be explored. Other RP materials and grease combinations should be investigated. One new RP material that should be examined is DuraForm PP 100 Plastic, a tough material, similar to the WaterClear. Because the grease retention shroud concept could be advantageous in maintaining critical grease lubrication in space mechanism applications, space-qualified greases should also be investigated further.

Appendix A

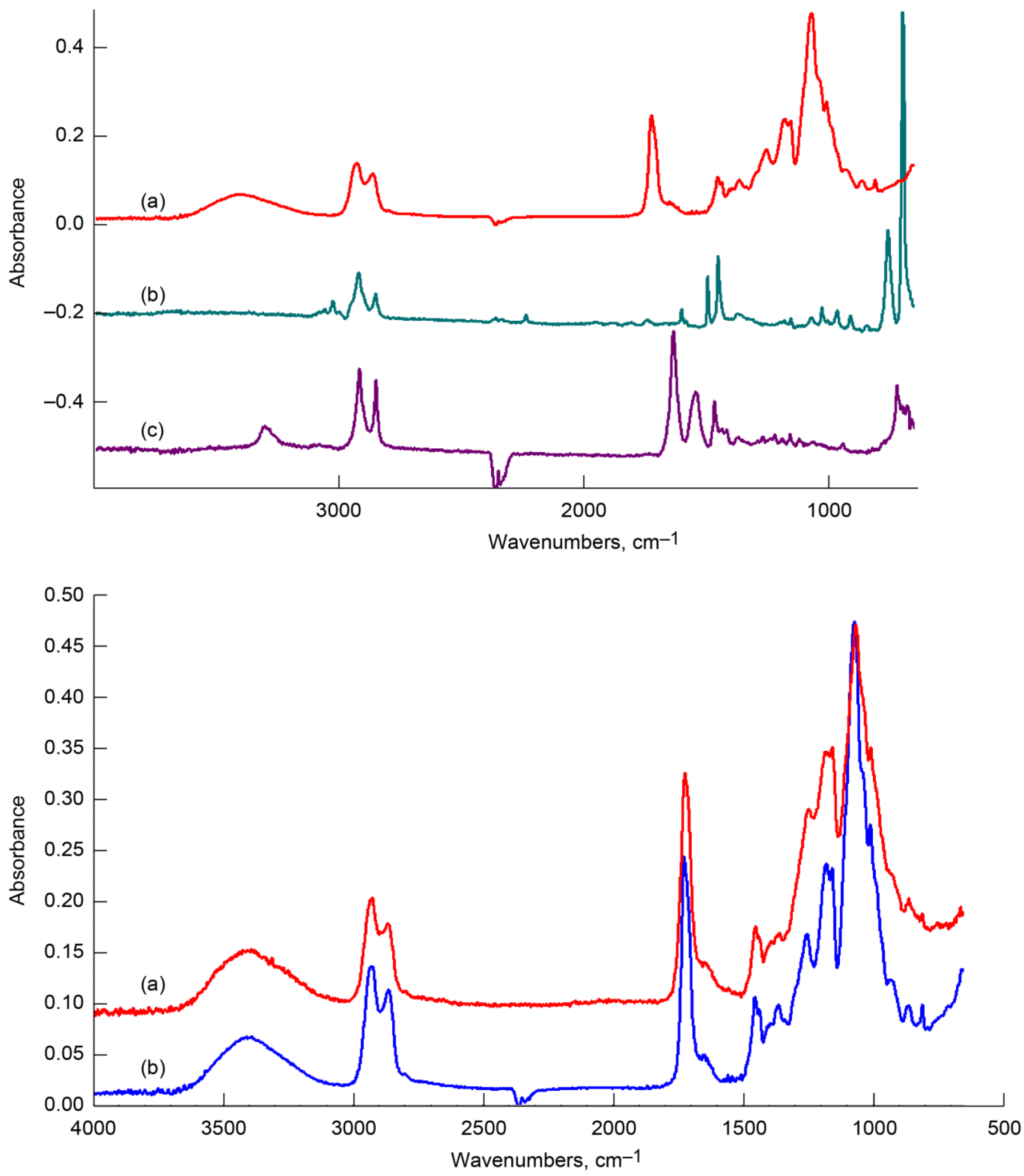

Figure 14.—FT-IR spectra of RP materials. Top: (a) WaterClear material, (b) ABS material, and (c) nylon material. Bottom: (a) Accura_60 material and (b) WaterClear material.

Appendix B.—Roughness Values

I and II are Mobilgrease and III and IV are Syn-Tech grease

Ra (micrometers) for Nylon material								
Time, hr	Before grease application				After grease application			
	I	II	III	IV	I	II	III	IV
19	13.0	13.4	13.9	13.1	11.5	14.8	11.1	11.0
47	16.5	10.9	13.1	12.3	13.9	13.4	9.9	12.2
67	10.1	10.4	10.1	10.1	11.4	12.4	9.5	8.1
90	11.2	13.8	13.8	10.5	10.1	8.6	10.1	8.2
163	12.5	13.3	13.8	10.5	11.8	12.8	8.8	8.7
239	11.1	12.4	12.1	8.7	11.1	9.8	10.1	11.3
331	14.0	10.9	11.5	11.2	10.3	8.0	10.1	8.0
428	11.9	10.8	10.1	11.0	11.2	12.1	10.61	11.2

Ra (micrometers) for ABS material								
Time, hr	Before grease application				After grease application			
	I	II	III	IV	I	II	III	IV
19	3.7	18.6	18.1	19.4	7.5	16.5	11.5	18.0
47	18.9	18.9	19.4	21.3	22.8	13.8	19.1	13.9
67	10.7	13.2	16.4	18.7	6.9	14.2	17.0	10.3
90	13.0	19.1	18.1	18.6	9.7	21.5	8.9	10.0
163	14.7	15.4	15.2	16.3	7.9	10.3	10.0	16.2
239	14.5	15.6	21.0	23.5	13.5	16.3	10.1	12.2
331	10.9	20.6	14.5	20.2	5.9	15.4	15.9	8.6
428	14.8	14.6	12.58	9.8	12.2	13.6	16.94	10.8

Ra (nanometers) for WaterClear 10120 material								
Time, hr	Before grease application				After grease application			
	I	II	III	IV	I	II	III	IV
19	516	261	149	196	292	494	449	212
47	160	118	107	129	131	134	183	310
67	253	170	143	222	392	350	289	459
90	137	90	144	98	192	226	241	178
163	318	233	190	119	157	218	295	547
239	238	99	142	234	199	121	529	345
331	169	188	183	111	985	306	217	226
428	130	87	185	148.3	245	212	231	114.15

Appendix III (A).—Surface Profiles of RP Material Nylon With no Grease

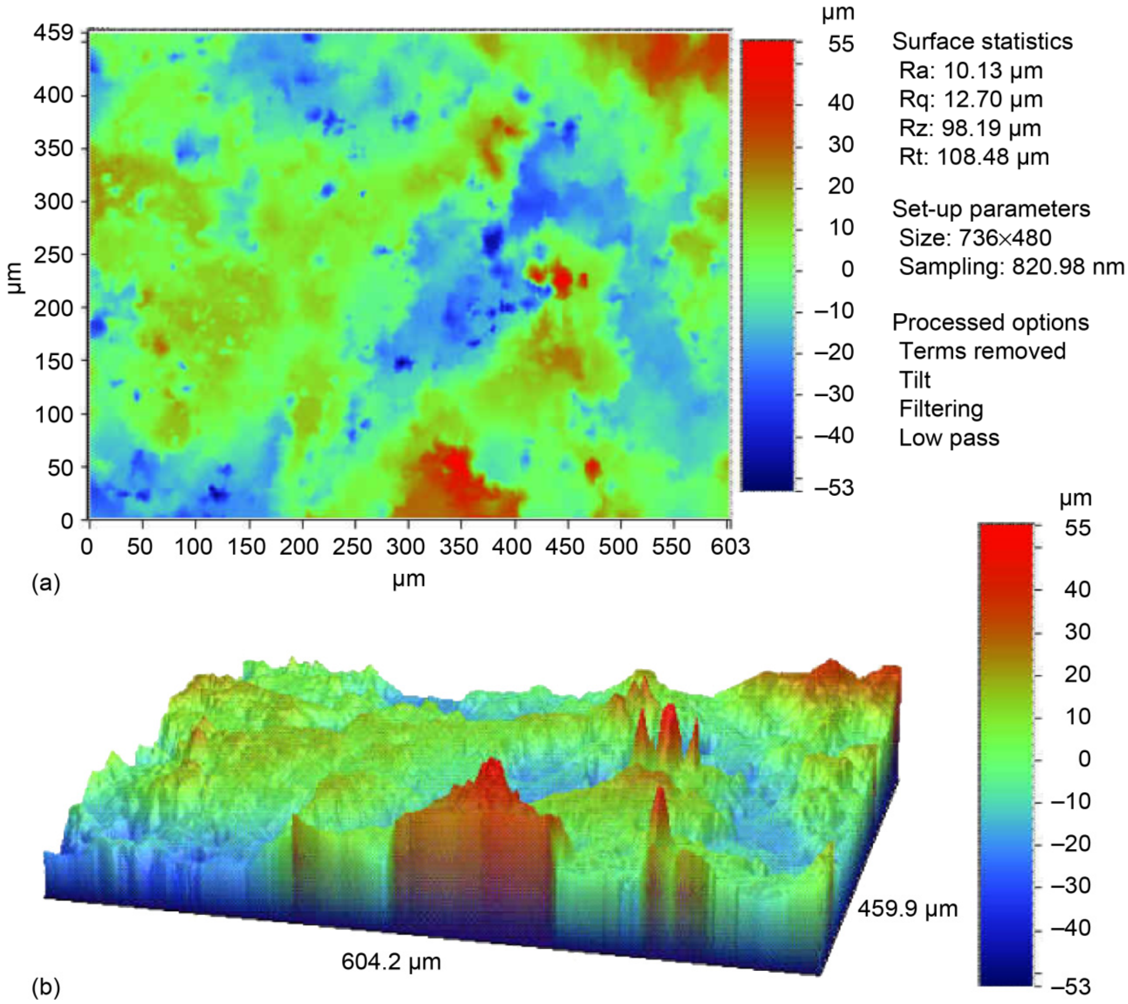

Figure 15.—Surface profiles of RP material nylon with no grease. (a) Top view and (b) 3-D view.

Appendix III (B).—Surface Profiles of RP Material Nylon With Grease

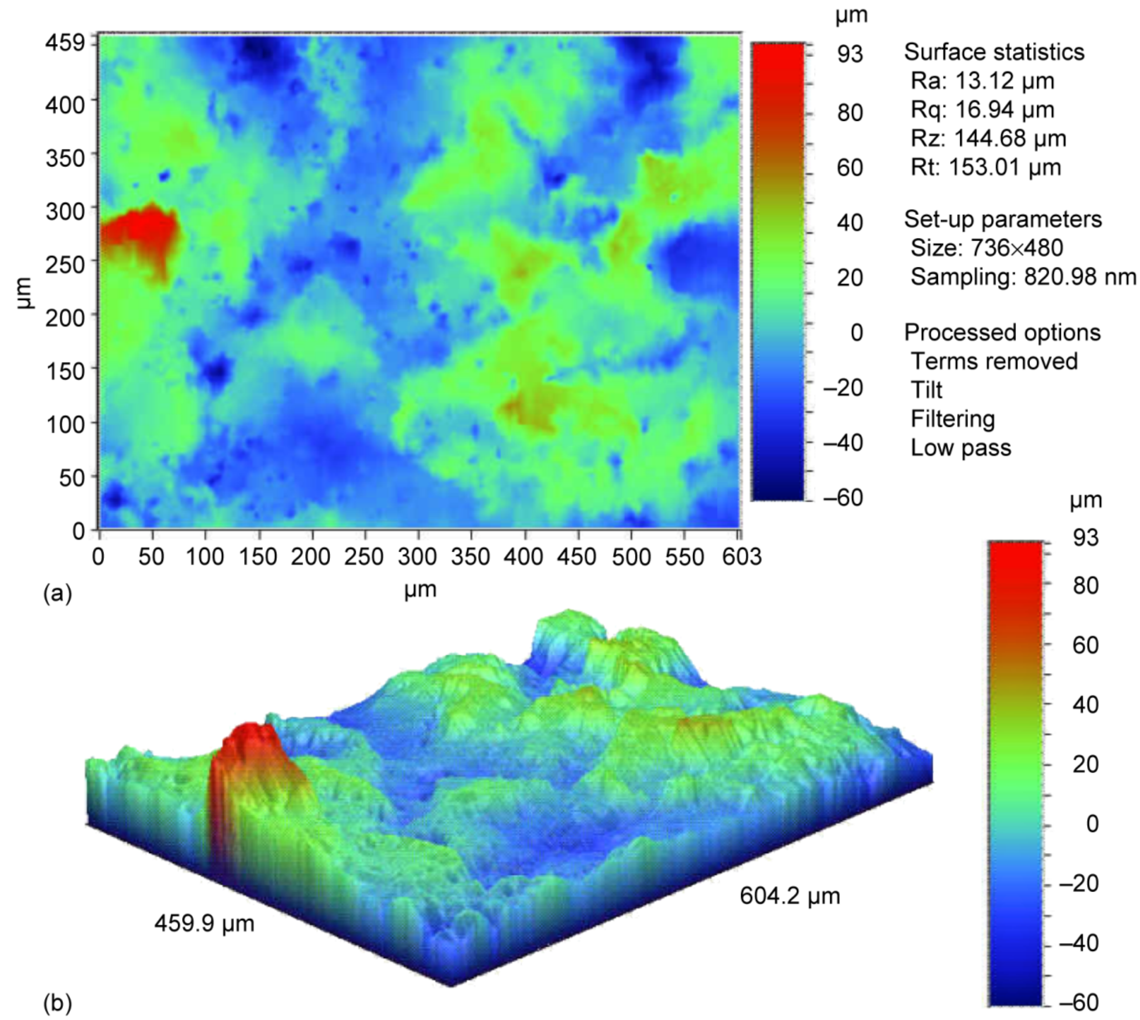

Figure 16.—Surface profiles of RP material nylon with grease. (a) Top view and (b) 3-D view.

References

1. Coy, John J., Townsend, Denis P., Zaretsky, Erwin V., “Gearing,” NASA Reference Publication 1152-AVSCOM Technical Report 84-C-15, 1985.
2. R. Handshuh, A. Zakrajsek, High Pressure Angle Gears: Preliminary Testing Results, NASA/TM—2010-216251, March 2010.
3. “Products | Materials | Duraform EX,” 3D Systems | Rapid Prototyping, Advance Digital Manufacturing, 3-D Modeling, 3-D CAD. July 2010 <http://www.3dsystems.com/products/materials/sls/duraformPA.asp>.
4. “FDM Material Properties,” ABS. Stratasys. July 2010 <http://www.vistatek.com/pdfs/FDM_ABS.pdf>.
5. “WaterClear 10120,” DSM Somos WaterClear 10120. July 2010 <http://www.dsm.com/en_US/downloads/dsms/datasheets/s10120product_data_sheet.pdf>.
6. “Veeco - Optical Profilers,” Veeco - Solutions for a nanoscale world. July 2010 <http://www.veeco.com/optical-profiler-systems/index.aspx?gclid=CNWdiL3nu KICFQoNDQodAmly5Q>.
7. “Mobilgrease 28,” MOBIL. July 2010 <http://www.mobil.com/Canada-English/Lubes/PDS/IOCAENGRSMOMobilgrease_28.asp>.
8. “Greases Designed Exclusively for Shaft Couplings,” KOP-FLEX. July 2010 <http://www.emerson-ept.com/catalogs/EPT/grease.pdf>.
9. “3D Systems." Accura 60 Plastic,” June 2010 < http://www.3dsystems.com/products /datafiles/datasheets/SLA/DS_Accura_60_US.pdf>

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE *(DD-MM-YYYY)* 01-12-2010		**2. REPORT TYPE** Technical Memorandum			**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Effects of Hydrocarbon-Based Grease on Rapid Prototype Material Used for Grease Retention Shrouds					**5a. CONTRACT NUMBER**
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Zakrajsek, Andrew, J.; Valco, Daniel, J.; Street, Kenneth, W., Jr.					**5d. PROJECT NUMBER**
					5e. TASK NUMBER
					5f. WORK UNIT NUMBER WBS 431731.04.01.03
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191					**8. PERFORMING ORGANIZATION REPORT NUMBER** E-17475
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001					**10. SPONSORING/MONITOR'S ACRONYM(S)** NASA
					11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2010-216896
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Categories: 37 and 23 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 443-757-5802					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Effects of hydrocarbon-based greases on specific rapid prototype (RP) materials used to fabricate grease retention shrouds (GRS) were explored in this study. Grease retention shrouds are being considered as a way to maintain adequate grease lubrication at the gear mesh in a prototype research transmission system. Due to their design and manufacturing flexibility, rapid prototype materials were chosen for the grease retention shrouds. In order to gain a better understanding of the short and long term effects grease pose on RP materials, research was conducted on the interaction of hydrocarbon-based grease with RP materials. The materials used in this study were durable polyamide (nylon), acrylonitrile butadiene styrene (ABS), and WaterClear 10120. Testing was conducted using Mobilgrease 28 and Syn-Tech 3913G grease (gear coupling grease). These greases were selected due to their regular use with mechanical components. To investigate the effect that grease has on RP materials, the following methods were used to obtain qualitative and quantitative data: Fourier transform infrared spectroscopy (FT-IR), interference profilometer measurements, digital camera imaging, physical shape measurement, and visual observations. To record the changes in the RP materials due to contact with the grease, data was taken before and after the grease application. Results showed that the WaterClear 10120 RP material provided the best resistance to grease penetration as compared to nylon and ABS RP materials. The manufacturing process, and thus resulting surface conditions of the RP material, played a key role in the grease penetration properties and resilience of these materials.					
15. SUBJECT TERMS Shrouds; Grease; Chemical analysis					
16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** STI Help Desk (email:help@sti.nasa.gov)
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	26	**19b. TELEPHONE NUMBER** *(include area code)* 443-757-5802